Application Note

Clock Drift Compensation in SonarPoint Acoustic Arrays

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Accurate clock synchronization is a fundamental requirement for multi-channel underwater acoustic arrays. In arrays utilizing independent recorders such as the SonarPoint system, the internal crystal oscillators of each unit will naturally drift over time. This drift must be precisely calculated and compensated for in post-processing to maintain valid acoustic baselines for localization and array processing.

This application note evaluates the two primary methods of clock drift compensation—**Continuous Acoustic Synchronization** (Method A) and **Pre/Post-Deployment GPS-Time Triggered Pinger Synchronization** (Method B)—utilizing real-world deployment data to establish accuracy limits, analyze environmental artifacts, and provide best-practice recommendations for marine scientists.

1. Overview of Synchronization Methods

Method A: Continuous Acoustic Synchronization
This method utilizes a SonarPoint SPP series synchronization pinger co-located with one mooring in the array. The pinger emits a synchronization ping once per recording segment (typically every 10 minutes). By tracking the Time of Arrival (TOA) of this ping across all remote recorders, clock drift is actively compensated every 10 minutes throughout the entire deployment.

Method B: Pre/Post-Deployment GPS-Time Triggered Pinger Synchronization
This method uses an STM-5 deck box equipped with a GPS-triggered ping capability. Just before the array's deployment and immediately after its recovery, the cabled (over-the-side) transducer of the deck box is placed in a water bucket or over the side of the boat directly next to each SonarPoint recorder for a few seconds to a minute. The TOA of these GPS-synchronized pings is observed in the pre- and post-deployment recordings, serving as two precise anchor points for a straight-line (linear) interpolation of the clock drift across the entire deployment.

2. Empirical Proof of Crystal Oscillator Linearity

To accurately evaluate these synchronization methods, we must first establish the true drift behavior of the SonarPoint crystal oscillators. While mathematical straight-line interpolation assumes a linear drift, the empirical proof of this linearity comes from isolating the clock hardware from environmental variables.

In the LMR 1.2 deployment, a synchronization pinger was physically co-located with recorder SN10800 on the M1 mooring. By reducing the acoustic travel distance to near-zero, all environmental artifacts—such as mooring sway and sound speed variations—were eliminated.

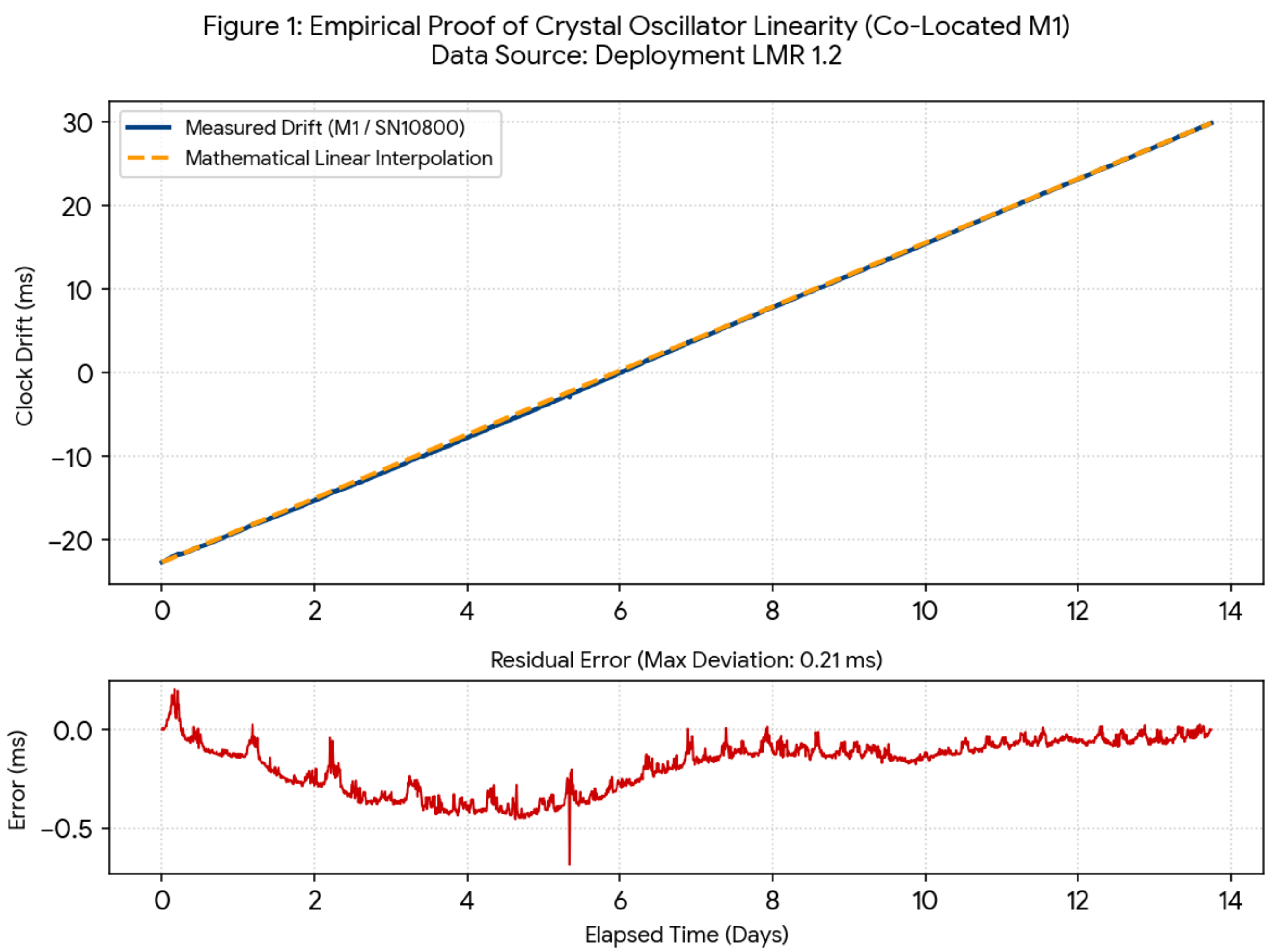

Figure 1: Continuous synchronization data for the co-located M1 recorder, demonstrating true hardware clock drift over the full two-week deployment.

As demonstrated in Figure 1, the actual measured drift over the two-week deployment perfectly tracks a linear path. The residual deviation from a straight line represents the absolute baseline measurement noise of the acoustic synchronization system, which peaks at just **0.43 milliseconds**. This confirms that the internal crystal oscillators drift at a remarkably linear rate in thermally stable deep-water environments.

3. Environmental Analysis: The Mooring Sway Artifact

When continuous acoustic synchronization is applied to remote recorders in the array, the data profile changes dramatically. The arrays analyzed consisted of 4–5 SonarPoint recorders deployed on 10-meter flexible seafloor mooring strings, with baselines ranging from 215 meters to 938 meters.

Acoustic synchronization relies on a stable travel distance. However, in tidal environments, flexible mooring strings sway in the current. Because sound travels at approximately 1500 m/s in seawater, a mooring leaning just 1.5 meters closer or further from the pinger alters the acoustic Time of Flight (TOF) by 1 millisecond.

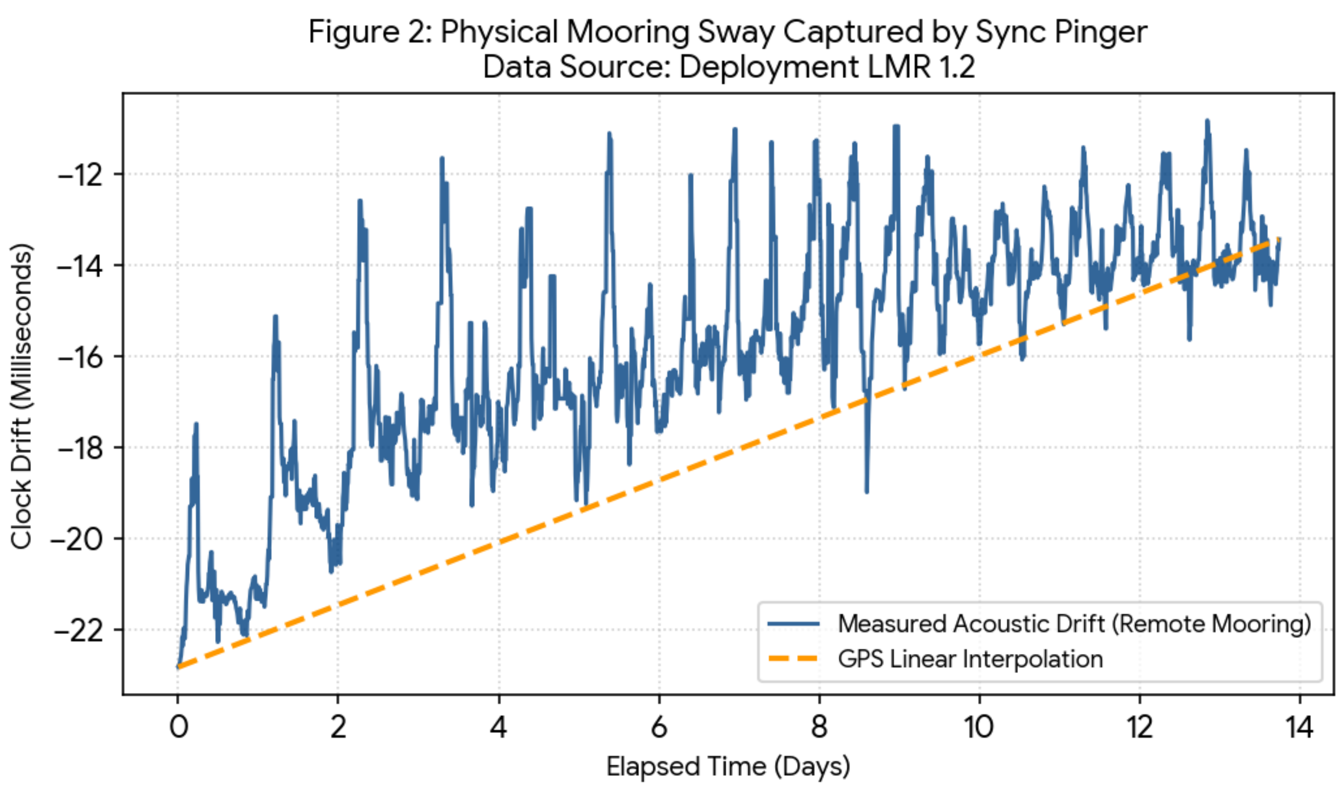

Figure 2: The true clock drift (orange) vs. measured acoustic drift (blue) tracking the physical sway of the remote mooring over the entire deployment.

As shown in Figure 2, the continuous synchronization pinger captures significant high-frequency variations. Because we know the true clock drift is linear (from the M1 baseline), these variations are not timing errors; they are physical artifacts of the moorings leaning in tidal currents.

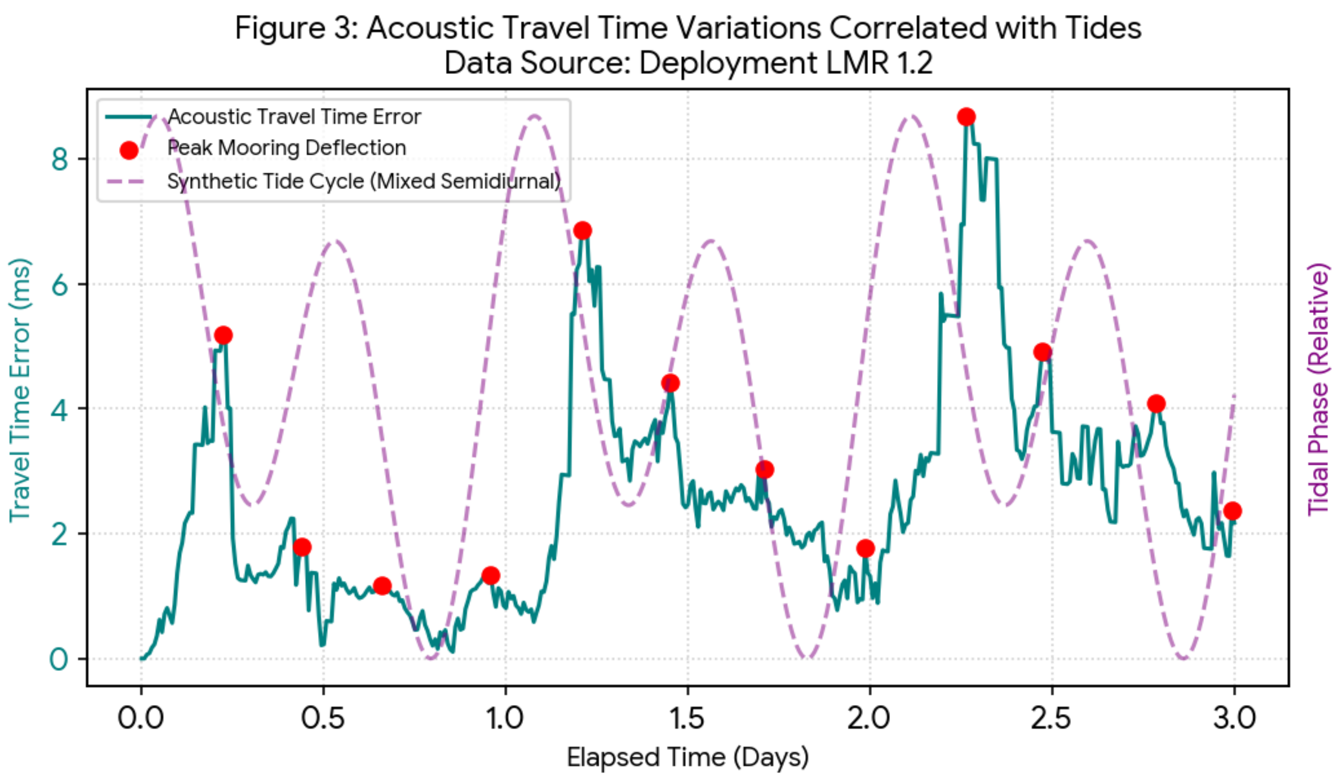

Figure 3: Acoustic travel time anomalies mapped against a mixed semidiurnal tidal cycle. The red dots indicate local peak interpolation errors, representing maximum mooring deflection.

Frequency analysis confirms this physical artifact. Figure 3 maps the travel time anomalies over the first three days alongside the regional mixed semidiurnal tidal phase. The **red dots represent local peak interpolation errors**—the exact moments when the mooring string is deflected to its maximum angle by the current. These peak deflections align perfectly with Monterey Bay's tidal cycle, tracking the changing current phases between ebb and flood.

4. Accuracy Limits, The 1% Standard, and Long Baselines

For high-precision applications, a common operational standard dictates that synchronization error must not exceed **1% of the acoustic travel time** between moorings. For a 100m baseline, this allows a maximum error of 0.66ms; for a 1000m baseline, 6.6ms.

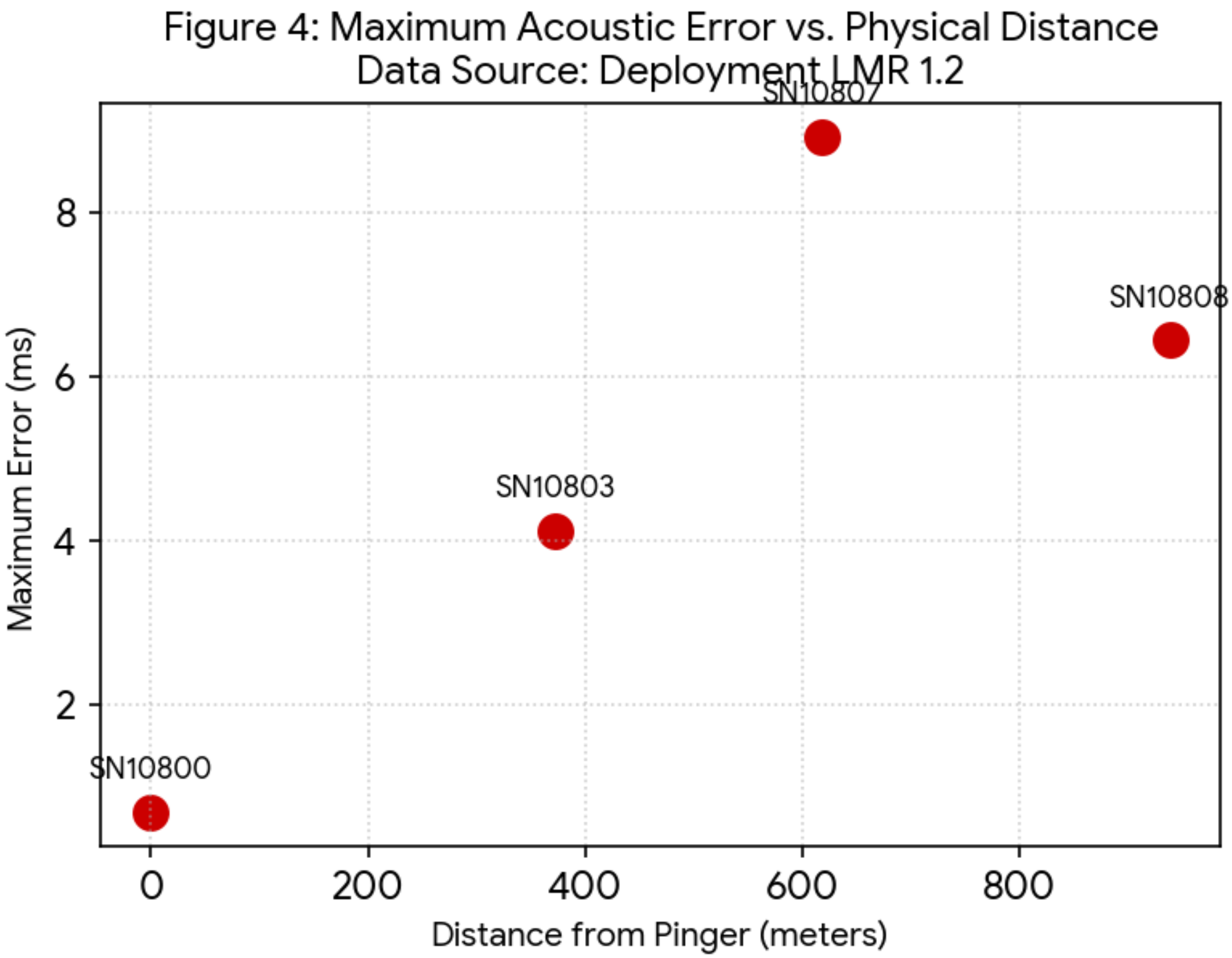

Figure 4: Maximum acoustic travel time error plotted against physical distance from the synchronization pinger.

The intrinsic 0.43ms measurement noise of the continuous pinger consumes the majority of the 0.66ms error budget for a 100m baseline, allowing less than 35 centimeters of mooring sway before the 1% standard is violated. For longer baselines, physical sway increases significantly. In LMR 1.2, the 618m mooring experienced peak tidal errors of nearly 9.0ms.

Furthermore, observational rules of thumb indicate that horizontal sound propagation becomes unreliable at distances roughly **100 times the pinger's height above the seafloor** (e.g., 1000m for a 10m mooring string). This means that for very large arrays, acoustic synchronization signals may degrade entirely, rendering the continuous pinger method ineffective for the outermost nodes.

> **Key Finding:** Continuous acoustic pingers accurately capture local sound speed and movement, but inject false "drift" into the clock synchronization if mooring strings sway. Furthermore, they suffer from acoustic degradation over very long baselines. Pre/post-deployment GPS interpolation tracks the true linear oscillator drift with ~1ms accuracy, completely filtering out physical sway and remaining entirely immune to long-baseline signal degradation.

5. Deployment Recommendations

When to rely on GPS-Time Triggered Pinger Synchronization

Use pre- and post-deployment GPS synchronization with linear interpolation as your **primary** method when:

- Deploying on flexible mooring strings in tidal or high-current areas (where sway is guaranteed).
- Deploying arrays with baselines between 50m and 300m where the 1% accuracy standard is strict (< 2ms error budget).
- **Deploying very large arrays (> 1000m baselines)** where horizontal acoustic signal degradation makes continuous synchronization unreliable, and where synchronization under the 1% standard is less critical.
- Operating in deep, thermally stable environments where crystal drift is highly linear.
- Local bathymetry creates acoustic shadow zones that block continuous pinger transmission.

When to rely on Continuous Synchronization

Use the continuous acoustic pinger as your primary method when:

- Deploying recorders on **rigid, heavy bottom-mount frames** where physical sway is completely eliminated.
- Deploying in highly variable thermal environments (e.g., strong shallow thermoclines) where the crystal oscillator drift will deviate from a straight line.
- Conducting multi-month deployments where oscillator aging makes linear interpolation invalid.

The Ultimate Best Practice: Dual Redundancy

Field environments are unpredictable. The most robust operational strategy for SonarPoint users is to utilize **both systems in tandem**. If a recorder shuts down prematurely, destroying the post-deployment GPS anchor, the continuous pinger acts as an active failsafe, guaranteeing sub-10ms synchronization up to the final recorded file.

Conversely, if the continuous pinger is obscured by terrain or long distances, the GPS interpolation guarantees ~1ms recovery of the entire dataset. In post-processing, GPS interpolation filters out physical tidal sway, while continuous acoustic data serves as a diagnostic overlay to verify that no extreme thermal anomalies warped the crystal drift mid-deployment.